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C O N T E N T S

100 YEARS OF THE BLAZHKO PHENOMENON: IS THE SOLUTION IN SIGHT ?

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Abstract. The Blazhko effect is a periodic amplitude and/or phase modulation of the light curve, shown by a large fraction of the astrophysically important RR Lyrae stars. Despite numerous observational studies and elaborate models attempting to reproduce the modulation, it still defies a definitive explanation. In this paper, I attempt to present a brief overview of the phenomenon, outline the proposed explanations, and conclude with the present status of research.

Key words: variable stars – pulsating stars – RR Lyrae stars.

1. INTRODUCTION: RR LYRAE STARS AND THE BLAZHKO EFFECT

RR Lyrae stars are pulsating variables with periods between 0.2 and 1.2 days. In the HR diagram, they are located on the horizontal branch and show brightness variations of the order of one magnitude. These stars play a key role in multiple applications for a range of astrophysical problems, such as distance determination (they follow a period-luminosity relation) and understanding old stellar populations (Smith 1995). Until recently, they were considered to display the simplest type of pulsation: radial pulsation, keeping their spherical symmetry throughout the pulsation cycle. RR Lyrae stars represent an outstanding testing ground for stellar evolution and pulsation theories.

Depending on their pulsation characteristics, RR Lyrae stars come in different flavors. The so-called RRab stars – pulsating in the radial fundamental mode – show the largest brightness variations, and (strongly) asymmetric light curves, whereas the RRc stars – which pulsate in the first overtone radial mode – have the smallest amplitude light curves and sinusoidal light curves. Finally, RRd stars pulsate in both radial modes simultaneously, resulting in more irregular light curves. However, the

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pulsation of RR Lyrae stars is not completely understood, and in particular one stubborn mystery has been haunting observers and theoreticians for one century now.

The most intriguing subclass of RR Lyrae stars consists of stars showing the Blazhko effect, the phenomenon of amplitude or phase modulation, which was observed for the first time by the Russian astronomer S. N. Blazhko in the star RW Dra (Blazhko 1907). The light curves of Blazhko stars are modulated on time scales ranging from a few days up to hundreds of days. Fig. 1 shows the modulation for a few Blazhko stars studied within the framework of our project (the Blazhko Project, see Section 4). The estimated incidence rate of Blazhko variables among the galactic RRab stars is about 20–30% (Szeidl 1988; Moskalik and Poretti 2003). For the RRc Blazhko stars this rate is less than 5%. In the LMC the incidence rate for RRab stars is only half as large (Alcock et al. 2000, 2003). The recent discovery of low modulation amplitudes (Jurcsik et al. 2005, 2006) leads us to suspect that the incidence rate of the Blazhko effect may be even higher. Maybe the non-modulated RR Lyrae stars are of a more uncommon kind.

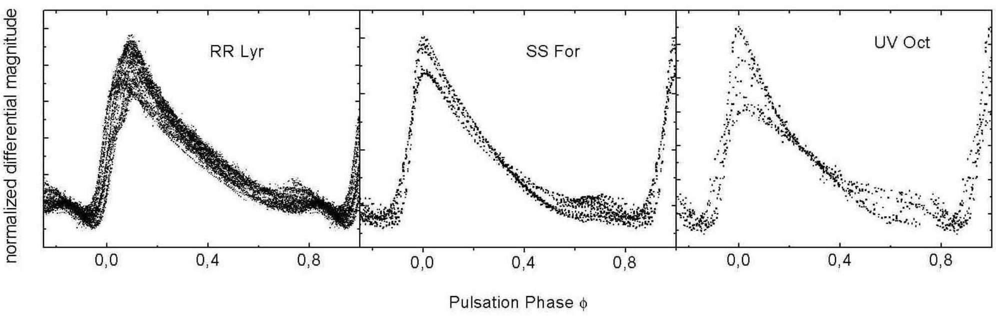

Fig. 1 – The Blazhko effect in three field RR Lyrae stars. The data were recorded within the framework of the Blazhko Project. For RR Lyrae, the prototype of the class, the Blazhko period was about 39 days at the time the observations were made (Kolenberg et al. 2006). For SS For, the Blazhko period is about 34.7 days, and for UV Oct it is about 143.9 days.

2. PROPERTIES OF BLAZHKO STARS

A typical feature of Blazhko stars is visible in their frequency spectra, where additional frequencies occur at the main frequency and its harmonics, ordered in equidistant triplet or doublet structures. In these multiplets the spacing between the frequencies is equal to the Blazhko frequency (Fig. 2).

In fact, these multiplet structures are predicted by the models proposed to explain the Blazhko effect (see Section 3). Nevertheless, the current models still encounter difficulties explaining the unequal amplitudes that are observed in the triplets of most Blazhko stars (see Fig. 2).

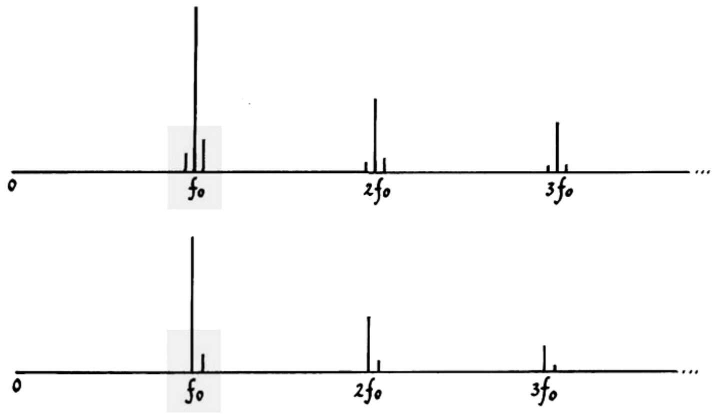

Fig. 2 – The typical frequency spectrum for a Blazhko RR Lyrae star. The frequency spacing in the triplets and doublets is equal to the Blazhko frequency. The same spacing occurs around the harmonic frequencies. Unequal amplitudes of the side peaks are a common feature.

Despite its clear signature in the light curves and in the frequency spectra, an important characteristic of the Blazhko effect is its irregularity.

In general, RR Lyrae stars are known to show a "noise" in their pulsation period changes, overlying the evolutionary period change (Smith 1995). Sweigart and Renzini (1979) propose that the period change noise is the result of changes in the internal structure of an RR Lyrae star, through random mixing events associated with the semiconvective zone of the stellar core. Other hypotheses – with varying predictive strength – to explain the (abrupt) period changes involve hydromagnetic effects in RR Lyrae stars (Stothers 1980), WIMPs (weakly interacting massive particles; Dearborn et al. 1990), light travel time because of motion in a binary system (Coutts 1971), or mass loss (Koopmann et al. 1993).

Moreover, changes in the modulation period were observed for a number of RR Lyrae stars, e.g., XZ Cyg (LaCluyzé et al. 2004) and RR Lyr (Kolenberg et al. 2006). As to pulsation periods, such changes occur on time scales too short to be of evolutionary nature.

It has been known since long that upon close inspection of the modulation there is not always an exact repetition of one Blazhko cycle to the next (see, e.g., Preston et al. 1965). This fact implies that either one cannot speak of a strictly periodic effect, or there must be more periodicities involved in the phenomenon.

Finally, some well-studied Blazhko stars display, besides their modulation period, even longer periods of the order of years. A cycle with a duration between 3.8 and 4.8 years was found for RR Lyr. At the end of the "4-year" cycle for RR Lyr, a shift in the Blazhko phase is observed (Detre and Szeidl 1973).

The facts given above imply that any explanation for the Blazhko effect must also account for its irregularity.

3. HOW TO EXPLAIN THE MODULATION?

The two most commonly quoted hypotheses to explain the Blazhko effect involve nonradial modes. This is striking as RR Lyrae stars have previously always been considered as prototypes of purely radially ($l = 0$) pulsating stars.

In the resonance models, the modulation is caused by a resonance between the radial mode and a nonradial mode of low degree. Model calculations revealed that dipole ($l = 1$; Fig. 3) modes have the highest probability to be excited through nonlinear interaction (Van Hoolst et al. 1998). In the frequency spectra triplet structures are expected to occur at the main frequency and its harmonics. In the scenario proposed by Dziembowski and Mizerski (2004), energy is transferred from the radial to the nonradial modes.

The magnetic models assume that Blazhko stars have a magnetic field strong enough to deform the radial mode to have additional nonradial pulsation components. Moreover, the symmetry axis of the magnetic field can be inclined with respect to the rotation axis of the star (oblique magnetic rotator). With rotation, our view upon the quadrupole components changes, causing the amplitude modulation. In the case of a dipole magnetic field, the radial mode is deformed yielding additional quadrupole ($l = 2$; Fig. 3) components. In the frequency spectrum, these components would give rise to quintuplet structures (Shibahashi 2000). However, depending on the geometry of the star's rotation axis and magnetic field axis, these quintuplets may appear as triplets. Quintuplet structures, as predicted by the magnetic models, are rarely observed, though we should mention their detection by Hurta et al. (2008).

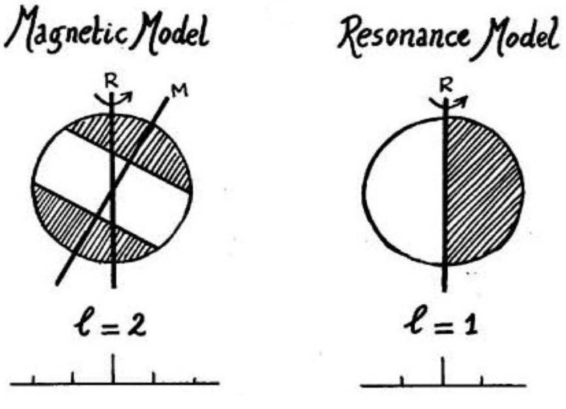

Fig. 3 – Schematic picture of the two most cited models to explain the Blazhko effect.

Magnetic field measurements have been published only for RR Lyr, the brightest Blazhko star. For this star the results have been differing: Babcock (1958) and

Romanov et al. (1994) detected a strong magnetic field, whereas Preston (1967) and most recently Chadid et al. (2004) contradicted these measurements and found no noticeable magnetic field in the star.

Though the aforementioned models are the most commonly quoted, they still lag behind in explaining the variety of features observed in Blazhko stars. Especially the unequal amplitudes in the side peaks pose a challenge, but also changing Blazhko periods, deviations from strict amplitude/phase modulation, the different occurrence rates for RRab and RRc stars, and the lower frequency observed in other populations such as the LMC. The deficiency of Blazhko star with pulsation periods longer than 0.65 days remains unexplained. Also this has to be addressed in the models.

In Blazhko stars the occurrence of additional peaks in the frequency spectrum is often interpreted in terms of the presence of additional modes, which cannot be radial (Olech et al. 1999). Recently, Gruberbauer et al. (2007) found evidence for additional modes in RRd stars as well. However, the nonradial nature of additional modes in RR Lyrae stars still has to be proven. Therefore, other paths for explaining the Blazhko effect have to be explored as well, also those involving only radial pulsation.

Stothers (2006) proposed a scenario in which variable turbulent convection, caused by a magnetic field which varies in strength, gives rise to the modulation. It is definitely worthwhile to investigate the role of convection in the Blazhko effect.

4. HOW TO GET CLOSER TO THE TRUTH?

In the past decades detailed studies of Blazhko stars have yielded valuable information on the phenomenology of the effect. The microlensing surveys provided a large database for statistics on the Blazhko effect (Alcock et al. 2000, 2003; Moskalik and Poretti 2003). Detailed studies based on multicolor millimagnitude photometry, e.g., the studies carried out by Jurcsik et al. (2005, 2006) revealed that very small modulation amplitudes may be common. They also found that the amplitudes of the side peak frequencies decrease less steeply than for the main frequency with increasing harmonic order, which may point towards a different nature of the underlying mode(s).

The important question whether nonradial modes are really playing a role in the Blazhko effect remains to be answered. Spectroscopic data offer the best diagnostics to find and identify nonradial modes. The first studies of this kind were carried out by Kolenberg et al. (2003) (see also Kolenberg 2002 and Chadid et al. 1999). The challenge in applying these techniques to RR Lyrae stars, however, is the strongly nonlinear behaviour of the radial mode. Therefore, adequate models must be used and techniques must be developed adapted to the nonlinear pulsation of RR Lyrae stars.

A suggestive image of the spectroscopic mode identification is given in Fig. 4.

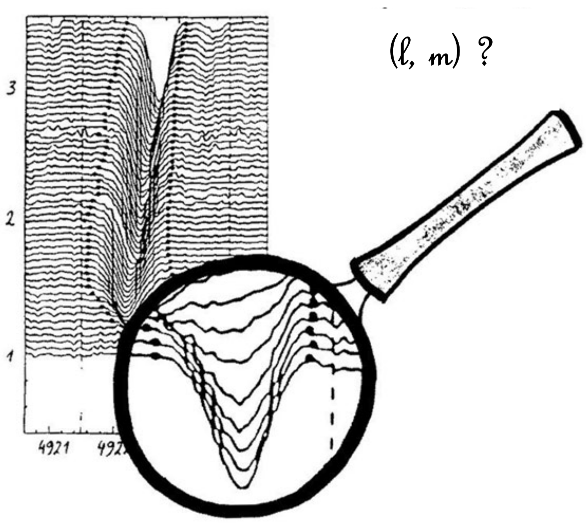

Fig. 4 – Spectroscopic mode identification: to find out the geometry of the small nonradial mode, the dominant radial mode has to be filtered out.

4. THE BLAZHKO PROJECT

The Blazhko Project is an international collaboration, set up to join efforts in obtaining a better understanding of the Blazhko phenomenon in RR Lyrae stars (Kolenberg 2005). The aim of the project is to combine spectroscopic and photometric data from a sample of well-selected Blazhko and non-Blazhko stars, in order to reveal decisive information on the physical mechanism responsible for the modulation. The project was founded (and is funded) in Vienna, and started its activities in 2004. A dedicated website gives the background, as well as the present status of investigations: `http://www.univie.ac.at/tops/blazhko/`.

The starting point for improving the modeling is an extensive data set of a limited sample of field RR Lyrae Blazhko stars in both hemispheres. Important is the inclusion of a few selected non-Blazhko RR Lyrae stars in the target list of which similar data are being gained, to be compared with the Blazhko stars. This is really important in order to answer the question what makes Blazhko stars different from their non-modulated counterparts.

The data set consists of high-resolution ($R > 40\,000$), high-S/N ($S/N > 100$) spectroscopic data evenly spread over the Blazhko cycle for the target stars. A few very detailed snapshots ($S/N > 200$) are obtained with telescopes in the 8-m class (HET, VLT), and will help to distinguish between different nonradial modes. Additional radial velocities over a longer time base can be obtained with smaller telescopes, and provide necessary information to interpret the line profile variations.

Finally and importantly, photometric data gathered over a time base of at least one year, are needed to ensure the required frequency resolution.

For the photometry, small telescopes are ideally suited. Therefore, the collaboration also involves amateur astronomers and makes use of robotic facilities in both hemispheres. It is unfortunate that professional observatories give in to the tendency to close down smaller telescopes in favor of larger-sized ones. Small telescopes complement larger ones and can yield important results, for example in variable star research. Moreover, they are an excellent training ground for astronomy students.

The photometric data are crucial for an extensive frequency analysis. For this purpose, methods using Fourier techniques, such as Period04 (Lenz and Breger 2005), and PDM (phase dispersion minimization, Stellingwerf 1978) are used. At the meeting in Athens, also a fruitful collaboration started using the Variable Sine Algorithmic Analysis (VSAA, Tsantilas and Rovithis-Livaniou 2007; see also this volume of proceedings) on RR Lyrae Blazhko stars.

One of the main assets of the spectroscopic data is that they enable us to get insight in the velocity patterns in the stellar atmosphere. As an example, the phase lag between the radial velocities derived from different spectral lines, the so-called Van Hoof effect, is interpreted as the time propagation of the pulsation wave through the atmosphere (Mathias et al. 1995). All RR Lyrae stars, especially those of type RRab, undergo large radial motions with high velocities. At distinct phases in the pulsation cycle, the atmospheres are known to be affected by shock waves, resulting in the broadening and even doubling of certain absorption lines, a peculiarity extensively studied by, e.g., Fokin (1992), Chadid and Gillet (1996). The above-mentioned phenomena show variable behavior over the Blazhko cycle (see, e.g., Preston et al. 1965) and their spectroscopic study can bring forth clues about the origin of the modulation.

The aims of this project are complementary to the already existing investigations focused on the Blazhko effect, particularly because of its emphasis on spectroscopy.

5. WHAT TO DO NEXT?

As we have mentioned above, the critical question that may be answered by means of the spectroscopic data is whether the nonradial modes are really present in modulated RR Lyrae stars. For the interpretation of the spectroscopic data in terms of pulsation modes we start from the available spectroscopic identification methods, such as the moment method (Aerts et al. 1992; Briquet and Aerts 2003), the pixel-by-pixel analysis (Schrijvers et al. 1997) and the Fourier Parameter Fit method (FPF, Zima 2006). However, these methods need adaptation from their original form for nonlinearly pulsating stars.

The development of accurate hydrodynamical models of RR Lyrae stars (e.g., Feuchtinger 1999) is essential for many applications. Given the tumultuous atmospheres of RR Lyrae stars, static atmosphere models are not really suitable to theoretically describe RR Lyrae stars in most pulsation phases.

One of the questions that can be answered with modern instrumentation is whether RR Lyrae stars do have a detectable magnetic field. So far results of spectropolarimetric measurements have only been published for RR Lyrae. A survey in search for magnetic fields in RR Lyrae stars in a sample of RR Lyrae stars, also non-modulated stars, started in December 2007 using the SEMELpol spectrograph.

Also the application of the Variable Sine Algorithmic Analysis (VSAA) method is very interesting, especially as several well-studied Blazhko stars show changing Blazhko periods, and common Fourier techniques encounter difficulties in revealing the true frequencies in this case.

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